

Water Use of Coal-fired Power Plants under Carbon Constraints

Haibo Zhai, Edward S. Rubin

Department of Engineering and Public Policy
Carnegie Mellon University
Pittsburgh, Pennsylvania

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Research Motivation

- Coal-fired power plants account for nearly 50% of the U.S. electricity supply and contribute one-third of the U.S. greenhouse gas emissions.
- To deeply reduce carbon dioxide (CO₂) emissions from coal-fired power plants, amine-based carbon capture and storage (CCS) is a key technology option.
- Currently, thermoelectric power plants account for about 40% of total freshwater withdrawals in the U.S., primarily for cooling.
- The U.S. Clean Water Act requires best available technology for most new power plants: from once-through to wet cooling towers.

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Objectives

- Quantify and characterize water use of pulverized coal (PC) power plants with wet cooling towers under carbon constraints, especially in conjunction with amine-based CCS.
- Identify the effects of key factors on water use at PC power plants with CCS.

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Integrated Environmental Control Model (IECM) for Power Plant Assessment

- A desktop/laptop computer model developed by CMU for DOE/NETL; free and publicly available at:

www.iecm-online.com

- Provides systematic estimates of performance, emissions, costs and uncertainties for preliminary design of
 - PC, IGCC and NGCC plants
 - Flue/fuel gas treatment systems
 - CO₂ capture and storage options



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Water Systems Module in the IECM

- A water systems module in the IECM was developed based on detailed mass and energy balances for coal-fired power plants (Zhai and Rubin, 2010; Zhai et al 2011).
- The water module is able to estimate water use for:
 - making up evaporation, blowdown and drift losses in wet cooling towers;
 - making up boiler blowdown losses;
 - water use (water washing or making up evaporation losses) in environmental control systems;
 - cooling the CO₂ capture process and making up water when applicable.
- The water module includes different cooling technologies: once-through, wet towers, and air-cooled condensers for dry cooling.

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Model Details Available in Publications

Energy Policy 38 (2010) 563–569

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Performance and cost of wet and dry cooling systems for pulverized coal power plants with and without carbon capture and storage

Haibo Zhai, Edward S. Rubin*

Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213, USA

<p>ARTICLE INFO</p> <p><small>Area history:</small> Received 10 February 2010 Accepted 6 May 2010 Available online 2 June 2010</p> <p><small>Keywords:</small> Cooling systems Pulverized coal power plant Carbon capture system</p>	<p>ABSTRACT</p> <p>Thermoelectric power plants require significant quantities of water. Water also is becoming critically important to greenhouse gas emissions from pulverized coal (PC) power storage (PCS) systems. We are reviewing considerable work that requires a significant amount of cooling. This paper reviews and cost of different cooling technologies for PC power plant an recirculating system with wet cooling towers, and a. We examine a range of key factors affecting cooling system including the plant steam cycle design, coal type, water availability, options for reducing power plant water costs</p>
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1. Introduction and objectives

Water is an integral element of electricity generation at thermoelectric power plants, primarily for the purpose of cooling. Thermoelectric power plants account for approximately 90% of freshwater withdrawals in the United States, a ranking slightly behind agricultural irrigation as the largest source of freshwater use (Poreley et al., 2008). Future water demands for electricity generation will increase as thermoelectric generating capacity is projected to grow by approximately 100% by 2030 relative to 2005 (NREL, 2009). To minimize adverse environmental impacts, the Clean Water Act (CWA) requires the use of best available control technologies for new power plants, which has promoted the widespread use of

the demand for water. Population and electric increasing possibility of water shortages that is (Desai and Srinivasan, 2007). water supplies, advanced cooling technologies in nuclear power plants or conventional systems (B) of power plant water use picture of the performance cooling technologies for power generation with C

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Water Use at Pulverized Coal Power Plants with Postcombustion Carbon Capture and Storage

Haibo Zhai, Edward S. Rubin,* and Peter L. Versteeg

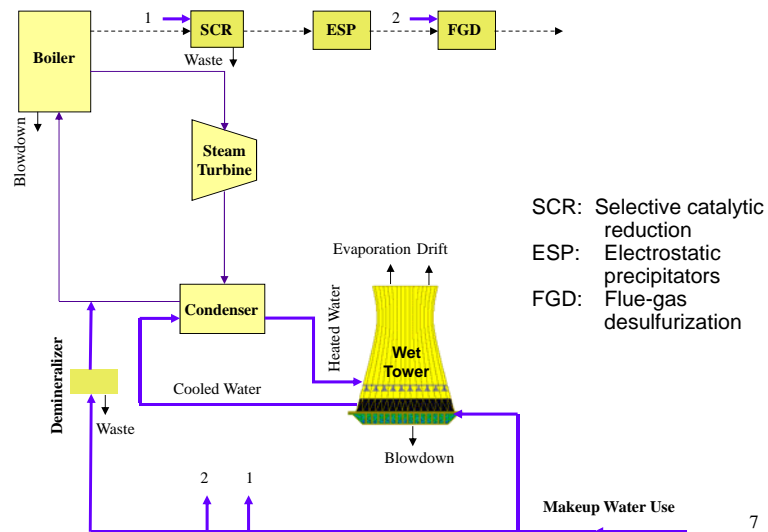
Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, United States

Supporting Information

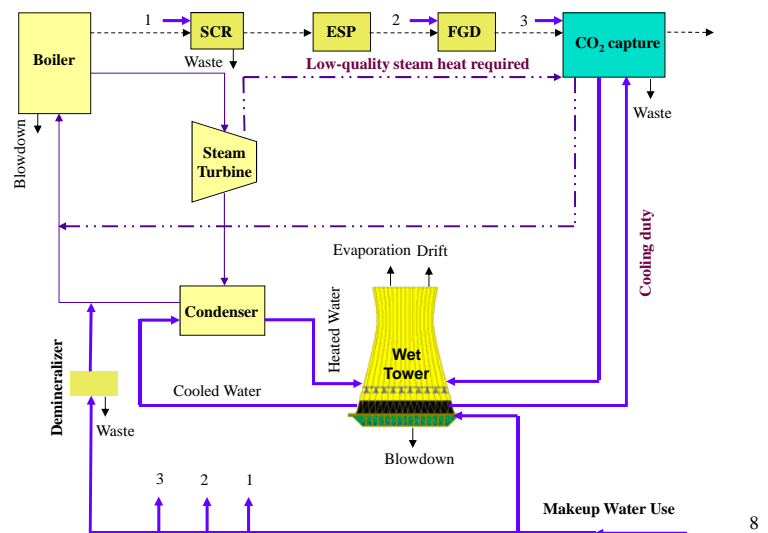
ABSTRACT: Coal-fired power plants account for nearly 50% of U.S. electricity supply and about 10% of U.S. emissions of CO₂, the major greenhouse gas (GHG) associated with global climate change. Thermal power plants also account for 30% of all freshwater withdrawals in the U.S. To reduce GHG emissions from coal-fired plants, postcombustion carbon capture and storage (CCS) systems are receiving considerable attention. Current commercial amine-based capture systems require water for cooling and other operations that add to power plant water requirements. This paper characterizes and quantifies water use at coal-firing power plants with and without CCS and investigates key parameters that influence water consumption. Analytical models are presented to quantify water use for major unit operations. Case study results show that for power plants with conventional wet cooling towers, approximately 80% of total plant water withdrawals and 90% of plant water consumption is for cooling. The addition of an amine-based CCS system would approximately

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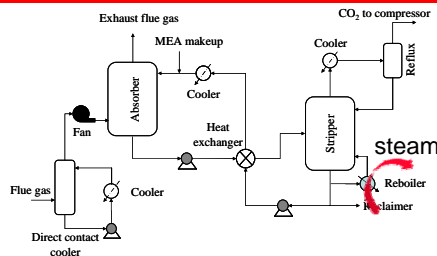
Water Configuration of A Coal-fired Power Plant without CCS



Water Configuration of A Coal-fired Power Plant with CCS



Major Performance Parameters of Amine-based CCS



Cooling water required to support

- Direct contact cooler
- Absorption process
- Stripping process
- CO₂ product compression

Parameter	Value
Capture system	Econamine FG+
CO ₂ removal efficiency (%)	90.0
Sorbent concentration (wt, %)	30
Temperature exiting direct contact cooler (°C)	45
Makeup water for washing (% of flue gases)	0.8
Regeneration heat requirement (kJ/kg CO ₂)	3517
Cooling duty (t H ₂ O/t CO ₂)	91.2

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Assumptions of Key Techno-Economic Parameters for Base Plants

Technical parameters	Value	Economic parameters	Value
Net plant output (MW)	550.0	Cost year	2009
Boiler type	Supercritical	Fixed charge factor	0.15
Net plant efficiency (HHV)	38.4%	Capacity factor	75%
Ambient air pressure (psia)	14.7	Life time (years)	30
Ambient air temperature (°C)	15	Labor fee (\$/hr)	33
Ambient relative humidity (%)	50	Water cost (\$/m ³)	0.26
Coal type	Illinois #6	Coal cost (\$/t)	46.3
Boiler blowdown rate	6.0%		
Cooling system			
Cooling technology	Wet tower		
water temp. drop range (°C)	11		
Cycle of concentration	4		
CO ₂ removal if applicable (%)	90		

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Key Performance and Cost Results of Power Plants with and without CCS

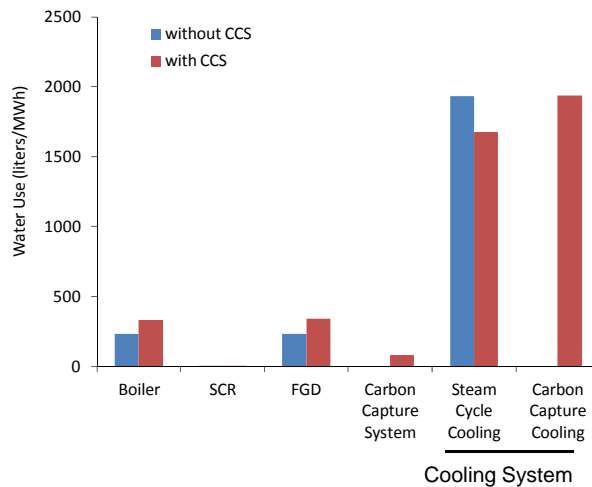
Variable	Without CCS	With CCS
Gross power output (MW)	590	685
Net plant efficiency, HHV (%)	38.4	26.4
Coal flow rate (tonnes/hr)	190.7	276.6
NO _x flue gas into SCR (tonnes/hr)	0.96	1.39
SO ₂ flue gas into FGD (tonnes/hr)	9.2	13.2
CO ₂ captured product (tonnes/hr)	n/a	590
Cooling water requirement (tonnes/hr)	53,530	100,200
Plant water use (tonnes/hr)	1,318	2,405
Plant cost of electricity (2009 US \$/MWh)	69.3	121.2

Adding CCS to a coal-fired plant for 90% would increase the plant water use by about 80%.

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Water Use Distributions for Power Plants with and without CCS

- The cooling system is the largest source of water use (80%).



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Sensitivity Analysis for Coal-fired Power Plant with CCS

- CO₂ emission standard
- Plant type
 - Subcritical
 - Supercritical
 - Ultra-supercritical
- Cooling technology
 - Dry vs. wet systems for steam cycle cooling

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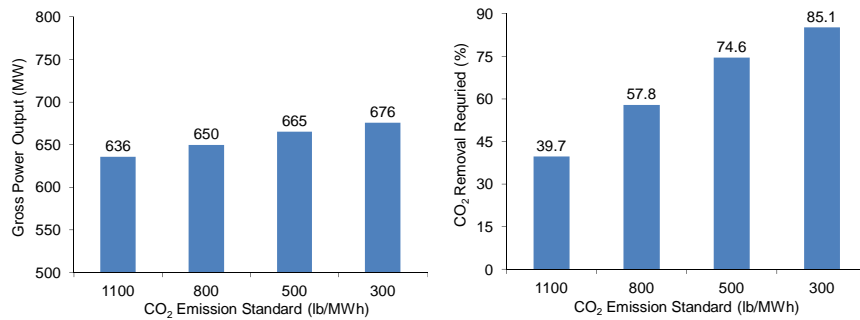
U.S. EPA Proposed CO₂ Emission Performance Standards for New Fossil Fuel Power Plants

- On Sept. 20, 2013, the U.S. Environmental Protection Agency issued a new proposal to limit CO₂ emissions from **new** fossil fuel power plants more than 25 megawatts, which would
 - require that **new** coal-fired power plants meet an electricity-output-based emission rate of **1,100 lb CO₂/MWh** of electricity generated on a gross basis.*
- In the proposal, CCS is identified as the best system of emission reduction. To meet the emission standard, **partial carbon capture** via CCS is needed for new coal-fired plants.

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Effects of CO₂ Emission Standard on Power Plant Performance

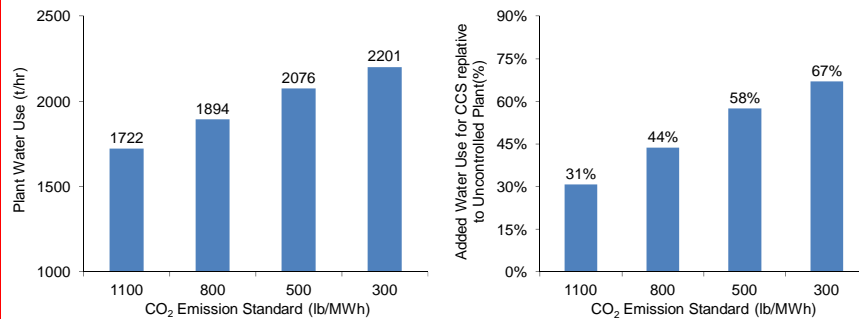
- A range of CO₂ emission limits from 1,100 to 300 lb/MWh and their water impacts are evaluated for a 550 MW-net PC plant using ver. IECM 8.0.



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Effects of CO₂ Emission Standard on Plant Water Use

Limiting CO₂ emissions from 1100 to 300 lb/MWh would increase the plant water use by roughly 30 to 70%.

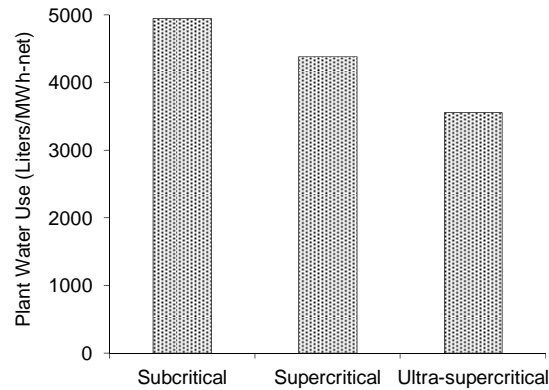


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Effects of Power Type on Plant Water Use

- The net plant efficiencies with CCS are 24.0%, 26.4% and 30.3% (HHV) for the subcritical, supercritical and USC plants with CCS, respectively.

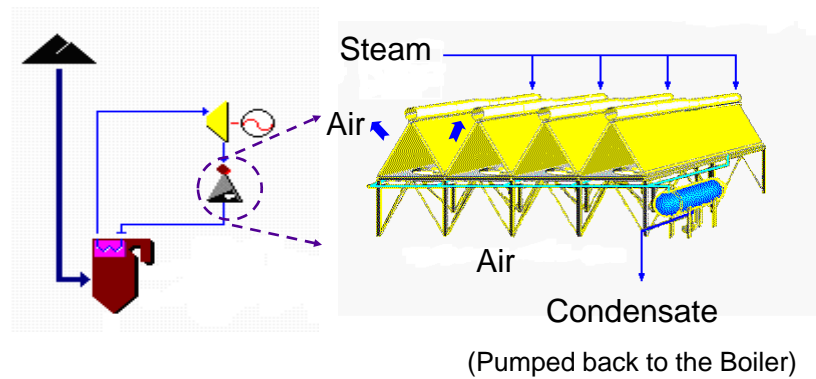
Improving plant efficiency would reduce the plant water use by 28%.



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Dry Cooling: Air-cooled Condensers

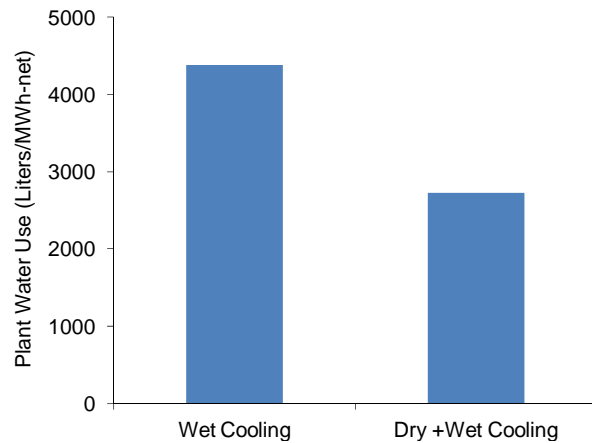
- Air-cooled condensers (ACCs) utilize the sensible heating of air passed through finned-tube bundles to reject steam heat for cooling.
- There is no cooling water used in the dry cooling for the steam cycle.



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Effects of Cooling Technology on Power Plant Water Use

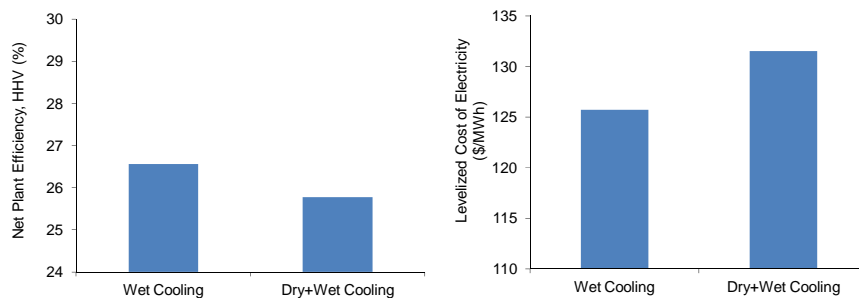
- Wet Cooling: wet cooling tower
- Dry + Wet Cooling: ACCs are applied to cool down the steam cycle and an auxiliary wet cooling system is used for the carbon capture system.



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Effects of Cooling Technology on Power Plant Performance and Cost

Replacing wet cooling with dry cooling would result in about 1% reduction in net plant efficiency and \$6/MWh increases in the plant LCOE.



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Conclusions

- The cooling system is the largest source of water losses at PC power plants with wet towers;
- Limiting CO₂ emissions from coal-fired power plants via CCS would significantly increase plant water use;
- Improving plant energy efficiency decreases plant water use;
- Replacing wet cooling with dry cooling would significantly reduce plant water use, but would increase the plant cost;
- There is a need for careful coordination of energy, climate change, and water resource policies to avoid a possible conflict between water supply and demand.

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Thank You

hbzhai@cmu.edu

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